Working Principle, Mechanism and Lift Effectiveness of Nanobiosensors

As A Food Perspective

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Abstract

Nanotechnology is a field of technology and science which is usually interested in particles that are smaller than 1-100 nm. This technology interested in atoms, molecules and related structures which has nanoscale dimensions. However, biosensors transform biological interactions into electronic signals that can be conveniently measured and recorded. Recently biosensors are combined by nanotechnology. This strategy can be seen as the key to yielding devices, which indicate rapid responses combined with high sensitivities. Nanotechnology can be ensured extremely high surface and small size nanostructures as nanotubes, nanowires and nanoparticles to biosensors applications. Nanobiosensors can be defined as biosensors, which are combined with nanotechnology by using several techniques. In this article, nanobiosensors are defined, thus the working principle, mechanisms and lift effectiveness are represented. At least, some food samples for nanobiosensors usages are given.

Keywords

Nanobiosensor; Mechanism; Food

Introduction

Nanotechnology is rapidly emerging technology, that is an interesting area for many kind of fields as biology, physics, chemistry, medicine, engineering (food, chemical, metallurgical and materials etc.), pharmaceutics etc. As a food perspective, nanotechnology applications in the area of food could be defined under four parts: food processing and improving functional products; delivering bioactive compounds and nutraceuticals and to their release; detecting of pathogens and improving food safety; developing packaging systems that might affect product quality and shelf life in a positive way (Senturk et al., 2013). Food safety would also potentially benefit from the introduction of nanobased sensors, detectors and labelling (Otles and Yalcin, 2012). Additionally, biosensors can detect a wide range of targets from small protein molecules to large pathogens. In a biosensor involving an electrically insulating base plate, an electrode system including a working electrode and a counter electrode formed on the base plate and a reaction layer formed on or in the vicinity of the electrode system, at least surface of the reaction layer is made porous, so as to ensure a biosensor of good response characteristic in which a reaction layer containing an enzyme dissolves quickly into a small amount of a sample solution and the enzyme reaction is effectively utilized (Miyamoto et al., 2004). Desired biosensors include specificity, accuracy, sensitivity, ease of use, reproducibility, near real-time assay and robustness. The number of false positive and false negative results of a biosensor should be very low, ideally zero, for it to be an acceptable practical device. Assay times less than 1 h are desirable since that is the essential characteristic that differentiates biosensors from conventional methods. Sensitive sensors are a must for the food industry since any false negative result could lead to an expensive recall and the loss of public confidence. Similarly false positives will increase cost to the manufacturer, and ultimately to the consumer. Reproducible and quantitative sensor responses are highly desirable. These sensors should be biochemically and mechanically robust and stable. Lastly they should be easy to use so that high level of training and skilled personnel would not be required. Additionally, types of biosensors could be classified as; optical biosensors (surface plasmon resonance, evanescent field fiber optic sensors, detection applications of fiber-optic biosensors), electrochemical biosensors (amperometric biosensors, potentiometric biosensors, impedimetric biosensors), acoustic wave

biosensors (bulk acoustic wave resonators), cantilever sensors (bending-mode cantilever sensors, resonant-mode piezoelectric cantilever sensors, pathogen assays) (Sharma and Mutharasan, 2013).

Nanobiosensors

Briefly the aim of nanobiosensor applications could be seen as a key to yielding device which exhibits rapid responses combined with very high sensitivities. Recently, consumer demand traceability and legislators and accountability in the food chain distribution has increased, the need for rapid and verifiable methods of food quality assurance has grown rapidly. Sensing technologies for food analysis including optical, chromatographic, and colorimetric and these kind of methods are employed. Biosensors permit the detection of analyte's wide spectrum in complex sample matrices, and have denoted great promise in areas such as food analysis, environmental monitoring and bioprocess. By the way, nanobiosensors are analytical tools which include nanotechnological particles or equipments, incorporating a chemical, biological or biochemical recognition component with a physicochemical transducer. The recognition component is capable of selectively interacting with an analyte directly or indirectly, emitting a signal through the transducer (Figure 1). The aim of such a tool is to produce either a continuous or discrete digital electronic signal that is proportional to a related group of analytes or a single analyte present in a sample. There are numerous types of biosensors which can be classified as; amperometric biosensors, electrode based biosensors, enzyme based biosensors, electrochemical biosensors, potentiometric biosensors, optical biosensors, tissue/whole organism-based biosensors (antibody and receptor-based biosensors), calorimetric biosensors wholecell based biosensors, immunosensors and acoustic biosensors (Bogue 2008, Connolly, 2008; Mansouri et al., 2008; Rana et al., 2010; Otles and Yalcin, 2010; Otles and Yalcin, 2012).

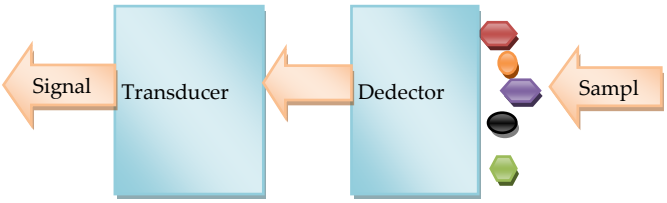

FIGURE 1. BASIC SHEME OF NANOBIOSENSOR WORKING PRINCIPLE

Working Principle and Mechanism of Nanobiosensors

Nanomaterials should be defined and known to understand mechanism and working principle of nanobiosensors. Thus nanomaterials can be classified as: carbon-based (tubes, particles etc), nanocomposites, metals and alloys [particles/ catalysts, Ag as antimicrobial, coating (old but new tribologicalproperties)], biological (protein, peptides, lipid nanocontainers, DNA templated circuits), nano-polymers (linear, branched, dendrimers), nano-glasses [amorphous materials: (SiO_2 – silicon dioxide-, ITO-Indium tin oxide-), Optical /photonics (LED)], nano-ceramics (crystalline materials). There are two approaches used to create nanomaterials, bottom-up and top-down. First one includes the manipulation of individual atoms and self-assembly to create complex nanomaterials from individual components. Self assembly naturally occurs in the body when nutrients are ingested and absorbed, and nutrition science presents a relevant example of selfassembly when amino acids are directed to form into proteins and enzymes. In the latter approaches, large materials are transformed into smaller ones. These kind of approaches contain solid state methods in which insular materials become conductive materials. Nanoparticles are the ultra small particles ranging from 1-100 nm that have unique physico-chemical properties, large surface to mass ratio, and high interactions in biological systems (De Corcuera, 2007; Nickols-Richardson, 2007; Otles and Yalcin, 2013; Zhang et al., 2008).

The electropolymerization step is one of the important step for nanobiosensors working. For that reason, several conducting polymers as polyaniline (PANI), polypyrrole (PPy) and polythiophene (PT) have been used as material coatings for the protection of common metals against corrosion. PPy films are the most popular ones, which easily synthesized at inert anodes as gold, platinum, stainless steel or glassy carbon by electrochemical oxidation of pyrrole or its derivatives in organic or aqueous media. Transferring the electropolymerization of these monomers to oxidizable metals is found much more difficult. The reason is the oxidation potentials of these metals are much more negative than that of the pyrrole and its derivatives and, hereby, dissolution of the metal will occur before electropolymerization begins. Consequently, to form PPy films on oxidizable metals, it is necessary to find electrochemical conditions which will strongly passivate the metal without impeding electropolymerization (Nalwa, 1996; Skotheim, 1997). According to another study, zinc and zincated steel are much more electropositive than iron or steel, and

under these conditions zinc dissolution remains extremely high and prevents pyrrole oxidation. Thus, in order to deposit PPy films on these metals two different strategies were adopted. The first consisted of a two-step process where, prior to pyrrole electropolymerization, the zinc surface was chemically or electrochemically pretreated with a sulfide solution and then pyrrole was electropolymerized in an aqueous solution containing oxalate ions. The latter one, more direct method, required only one step in which the treatment of the Zn surface and the electropolymerization of pyrrole occur simultaneously when small amounts of sulfide ion are mixed with the oxalate solution at pH 5 (Aeiyach et al., 1999; Ferreira et al., 1996; Petitjean et al., 1999; Zaid et al., 1998).

Transparent conducting oxides (TCOs) have long been a subject of various investigations due to its unique physical properties and applications in commercial devices. Among these materials, ZnO is one of the most promising one for the fabrication of the next generation of optoelectronic devices in the UV region and display or optical devices. They are used as gas sensors, solar cells, surface acoustic devices and transparent electrodes. Zinc oxide has a wide band gap, high transparency and low resistivity in the visible range and high light trapping characteristics. However, undoped ZnO thin films are not stable due to changes in the surface conductance under oxygen adsorptions and chemisorptions (Ayouchi et al., 2003; Baxter and Aydil, 2006; Caglar et al., 2007; Kim et al., 2006; Mikami et al., 2006; Nunes et al., 2002; Sahu et al., 2006; Water et al., 2002; Xu et al., 2007; Yoo et al., 1990; Zhao et al., 2005; Zou et al., 2006).

Characterization of Nanobiosensors

Control of nanostructural formulation of nanobiosensors can be done by using advanced equipment. The molecular technologies (as molecular-assembly) has been denoted and controlled by using advanced equipment which have been developed as atomic force microscopy (AFM), brewster angle microscopy (BAM) etc. AFM is a method that ensures detecting nanoscale structural information. X-ray diffraction (XRD), transmission electron microscope (TEM) and scanning electron microscope (SEM) were also evaluated as equipment to determine the degree of nanoparticle's exfoliation. Atomic force microscopy (AFM) is a nanoscience device or microscopic tool that has been used to ensure new information on the molecular structure, map surface roughness or composition of food materials. As an imaging tool it has led to solutions to previously intractable problems in food science. This type of information can represent a basis for tailoring food structures to optimise functional behaviour. It is also considered that the potential for the use of force spectroscopy to detect specific intermolecular interactions believed to be responsible for the bioactivity of food polysaccharides (Morris et al., 2011; Otles and Yalcin, 2013; Pereira et al., 2008; Rodríguez Patino et al., 2007; Yang et al., 2007).

Lift Effectiveness of Nanobiosensors

There lots of parameters which are affected nanobiosensors working. Some important ones are described. One of these, chemical doping with foreign atoms is an effective method to intrinsically modify the properties of host materials (Wang et al., 2010). The experimental results denotes that tin doping of zinc oxide thin films improve the sensor element sensitivity to 1.5 ppm NO_2 in air and downshift the operating temperature (Shishiyanu et al., 2005). Effect of In, Al and Sn dopants on the structural and optical properties of ZnO thin films have been investigated by X-ray diffraction technique and optical characterization method. X-ray diffraction patterns establish that the films have polycrystalline nature. The grain size values of the films are found to be 29.0, 35.2 and 39.5 nm for In, Al and Sn doped ZnO thin films, respectively. The optical band gaps of the films were established to be approximately same values. The inclusion of dopant into films expands also width of localized states as $EU_{In} > EU_{Al} > EU_{Sn}$. The refractive index dispersion curves obey the single oscillator model. The dispersion parameters and optical constants of the films were established. These parameters changed with In, Al and Sn dopants (Caglar et al., 2007). From another perspective for the ZnO film studies, it was clearly denoted that the electromechanical coupling coefficient and insertion loss of ZnO-based surface acoustic wave devices could be noticeably improved by Cu-doping (Lee et al., 2001). Additionally, both undoped and doped (Mn or Cu) ZnO films were prepared by a sol–gel method. The films were transparent and consisted of single phase ZnO with zincite structure. All the films denoted preferred orientation in c-axis and both Mn and Cu doping decreased the extent of orientation. Cu doping increased the grain size of the films while Mn doping slightly decreased it. Both doping elements increased the surface roughness of the ZnO films and the width

of the band tails, and decreased the band gaps (Bahşi and Oral, 2007). Sn dopant greatly increased gas response of ZnO to formaldehyde, Fe dopant increased a bit at the maximum and decreased a bit beyond the maximum, while Ti dopant decreased the gas sensing property of ZnO. The UV–vis spectra and morphology denoted no close relationship with the modified gas response of ZnO. From Raman spectra and XRD pattern, Ti and Sn dopants lead to a secondary phase besides ZnO crystal, which are low gas sensing rutile TiO_2 and high gas sensing SnO (Han et al., 2010). Also, a titanium sol–gel derived optical biosensor encapsulated with glutamate dehydrogenase was fabricated using the vapor deposition method. The vapor deposition method was denoted to effectively immobilize enzymes on the glass matrix. After optimizing the deposition time and temperature, a transparent titania sol–gel film was established, which could immobilize biomolecules for optical determination. SEM and AFM images denoted that enzymes doped into titania sol–gel film significantly changed the surface morphology. Glutamate might be efficiently detected by using the TiO_2 sol–gel derived biosensors. The biosensors also denoted good analytical performance with dynamic range of 2–3 orders of magnitude. Additionally, the detection responses of glutamate in biological samples also denoted good performance, and the analyte range was from 20 to 10,000 μM with the detection limit of 6.7 μM. Furthermore, even after long-term storage, the prepared biosensor retained high relative enzyme activity and precise detection. It can be exemplified that this simple vapor deposition method can be successfully utilized to form transparent titania sol–gel film for the fabrication of biosensors that is suitable for optical detection of glutamate in water and biological samples (Doong and Shih, 2006). All the films were polycrystalline with the ZnO hexagonal Wurtzite type structure. Except for In, dopant concentration in the film is less than that in solution. By the way, dopant introduction modifies the film growth process; this fact might be used to acquire strongly c-axis-oriented films. For all the ZnO doped films analysed, it could be observed that film growth goes from non oriented growth, for undoped films. Therefore, the films are strongly c-axis oriented, at least for some range of the dopant concentration, in all the dopants used. Also, the surface morphology also is strongly affected by the introduction of newer nucleation centers. TEM and SEM micrographs clearly denote the influence of the amount and type of dopant in the microstructure of the film. This type of variation in film microstructure might explain the enhanced response of Al and Sn doped ZnO films to ethanol ambient (Paraguay et al., 2000a). Changes in the conductivity as a function of temperature suggest that their magnitude is determined by three basic mechanisms: electron activation, oxygen adsorption, and oxygen desorption. It is denoted that doped ZnO thin films deposited with a spray pyrolysis system could have high sensitivity to ethanol vapour. Al and Sn dopants gave the highest sensitivity in the working temperature of 675 K (Paraguay et al., 2000b). Doped thin films offer the stable low temperature Sn-doped ZnO structure and the sensor sensitivity is related to the film morphology. It was experimentally indicated that tin impurities in ZnO films improved sensors gas-sensing properties to NO_2 and produce a shorter response time. It is possible to tune these parameters by varying the film porosity and Sn concentrations in the solution. As a result, highly porous film sensors have a high sensitivity, but a longer response time. These experimental results denote that conductometric gas sensors based on tin-doped ZnO as sensitive layer are of great interest for NO_2 detection. Also, chemical processes permit the production of inexpensive sensors in a simple manner (Shishiyanu et al., 2005). The application of Rietveld refinement method to analyse X-ray diffraction spectra has been shown as an effective method to acquire more detailed information about the crystallographic structure of the ZnO films. Results of this method clearly denote the influence of dopant concentration on the microstructure of the films. Small In amounts causes decreasing lattice parameters. Then, with further In insertion an increase of these parameters is observed. Domain size denotes an opposite variation to lattice parameters: it initially increases as the In contents grow; from 50 nm for undoped films to more than 100 nm at 1 at.%, then it decreases gradually to approximately 50 nm for In concentration higher than 3 at.%. Preferential growth orientation was dependent of the In contents. (Miki-Yoshida et al., 2000). Highly transparent and electrically conductive films of undoped and doped ZnO could be also prepared by pyrolytic decomposition of zinc acetate. It was found that boron acts as effective donor in ZnO. The optimum doping content of boron is 0.8 wt%. The films obtained with 0.8wt% doping of boron present low resistivity. The average transmittance was found to be 90% for all boron doped films. X ray diffraction

studies denote that films are crystalline and well oriented along the (0 0 2) plane (Lokhande et al., 2001).

Nanobiosensor Samples and Importance For Food Sector

Recently, nanotechnology has been indicating great progress in many areas and it is started to grow rapidly in the food industry. Nanotechnology promises significant improvements for the future in the food industry with many potential applications that is the field of product improvement, food processing, food packaging and safety. By the way, nanotechnology and its applications could give chance to produce functional foods, effective usage of food components, reuse of components or microorganisms by encapsulation systems, controlled food packaging by applying sensors or intelligent/smart packaging systems and therefore inhibit the wasting of product or controlling of product during production chain. Applications of nanotechnology in the food industry have been developing more slowly than other areas because of their complex structures and sensitivity. Thus, the application of nanotechnology in food industry is based on chemical process between food materials, food contact materials (packaging materials) and nanomaterials, as a principle of chemical interactions. Especially, packaging industry has been denoted great development because of nanosensors which are used for detection of toxic substances and microbiological degradation effectively and quickly and so prevent consumption of spoilage or contaminated products. As a result, biosensors could be a thrilling alternative to the traditional methods for the detection of toxins and pathogens in food (Otles and Yalcin, 2013; Senturk et al., 2013).

Bacterial biosensors are a challenging alternative as their simplicity, easiness to produced and highly accurateness. A set of bacterial biosensors are described, based on a nonpathogenic laboratory strain of *Escherichia coli*, the natural resistance mechanism of *E. coli* against arsenite and arsenate, and three reporter proteins: bacterial luciferase, Green Fluorescent Protein (GFP) and β-galactosidase. For arsenite, field testing is achieved with a system which included β-galactosidase, producing a visible blue color at arsenite concentrations above 8 μg/L (YiTao and MengNi, 2009). By amperometric method *E. coli* detection based on the integration of self-assembled monolayers (SAM), enzyme amplification, microelectromechanical systems (MEMS) and DNA hybridization was reported. This analysis was performed with a few microliters solution volumes in 40 min. 1.000 *E. Coli* cells could be detected without polymerase chain reaction with high specificity for *E. Coli* vs. the bacteria *Bordetella bronchiseptica* (Bogue, 2008). According to another study; a gas-phase sensor for the detection of basic amine spoilage products in packaged fish is described. The change of the sensor is visual and can be measured against a reference colour around the sensor, though if quantization is required a colorimeter or imaging system could be employed. (Crowley et al., 2005; Otles and Yalcin, 2012). Some other food nanobiosensor samples are given in Table 1.

TABLE 1 SOME FOOD NANOBIOSENSOR SAMPLES

Sopport for immobilization	Storage Stability	Application	References
Self-assembled biotinylated phospholipid membrane	5 days		Rehak et al., 1994
CuptCl6/GC	7 days (30% retained)		Pei and Li, 2000
c-MWCNT/PANI	100 days (50% lose)	Fish Meat	Caruso et al., 2001
Modified graphite	470h		Dimcheva et al., 2002
Double walled carbon nanotube		Fish Samples	Zu et al., 2002
Nafion	10 days	Fish Meat	Nakatani et al., 2005
Au-NPs/GC	7 days (18% retained)	Fish Meat	Cubukcu et al., 2007
Graphite powder modified ferrocene + eicosane + PVC	35 days (60% lose)	Theophylline	Gao et al., 2009
Didodecyldimethylammonium bromide (DDAB) + tetrathiafulvalene (TTF)			Teng et al., 2010
ZnO-NPs–PPy	100 days (40% lose)	Fish Meat	Devi et al., 2011
AuPPy	100 days (40% lose)	Fish, chicken, pork, beef meat	Devi et al., 2012a
ZnO-NP/CHIT/c-WCNT/PANI	30 days (30% lose)	Fish	Devi et al., 2012b
AgNPs	60 days (20% lose)	Fish, chicken, pork, beef meat	Devi et al., 2013

Conclusion

In recent years, nanotechnology finds lots of application on different kinds of field. Food sector is one of these fields. According to increase on the ready to eat food and diversity of food the food quality, safety and production step control gain major importance. Because of long time period, high cost of food analysis and non-portable food analysis devices, the food analysis are getting harder and risky during the production periods. The alternatives for these kind of problems could be found by entegration of new technologies. At this point, nanobiosensors as an entegration of nanotechnology and biosensors (alternative, rapid response, sensitive devices) could be used in food analysis. Need for a more rapid, reliable, specific and sensitive method of a target analyte detecting, at low cost, is the focus of many research. Biosensors are portable, inexpensive suitable and easy-to use analytical tools. Under environmental conditions, biosensors repeated use with complex sample matrices and the long-term storage is a remaining challenge. Biosensor technology has the potential to increase specificity and sensitivity, enable high-throughput analysis, speed up the detection and to be used for critical control points monitoring in food production. Chemical doping with foreign atoms, type of dopant materials could be enhanced, improved or increased positive properties to biosensors as sensitivity, suitability, easy to use.

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